LISA-SC-DD-0002

Laser Interferometer Space Antenna (LISA)

Propulsion Module Description

Original

Publication Date: 15 Jan 09

Expiration Date: TBD

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

NOTE:

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE BY NASA-GSFC EXPORT CONTROL OFFICE (CODE 274) IN ACCORDANCE WITH EXPORT CONTROL INTERNATIONAL TRAFFIC IN ARMS (ITAR) REGULATIONS, 22 CFR 120-130. GSFC ITAR FORM 25-49 DATED 12/04/08 IS ON FILE.

TABLE OF CONTENTS

Section/Title Page #

1 Propulsion Module Overview

The Spacecraft (S/C) is defined as the Sciencecraft (spacecraft bus + payload) integrated with the Propulsion Module (P/M) as shown in Figure 1.1.

The P/M utilizes a chemical bi-propellant propulsion system to provide the delta-v required to transfer the S/C from its post-EELV separation low earth orbit to its operational science orbit. Upon reaching the final orbit, the P/M separates from the S/C and is appropriately discarded. The primary requirements for the P/M are as follows:

1. Provide the delta V capability to transfer and orient the S/C from the EELV insertion/separation phase to the required science orbit
2. Provide support to the Sciencecraft during ground operations
3. Provide the primary load path for the S/C during launch

The P/M design accomplishes the above requirements with a design that includes:

- A structure that supports all of the propulsion subsystem elements, provides a stiff interface with the launch vehicle and supports the SC
- Propulsion subsystem elements (propellant storage, regulation & distribution and thrusters)
- All electrical harness linking the propulsion subsystem and thermal hardware internally and to the SC interface (the SC will provide all power, thermal control, and control functions to the P/M)
- A thermal subsystem (e.g. including but not limited to: MLI, thermal spacers, heaters, paint, thermistors/thermostats etc) to maintain the P/M temperature within acceptable limits

Mission baseline parameters driving the Propulsion Module design are shown in Table 1.1-1.

Note: The Mission Design Lab (MDL), GSFC, conducted a design study for LISA Project in January 2008, and is the basis for the propulsion system and associated analysis.

1.1 Propulsion Module Mechanical Design

Mission baseline parameters driving the LISA Propulsion Module Mechanical System Design are referenced in Table 1.1-1.

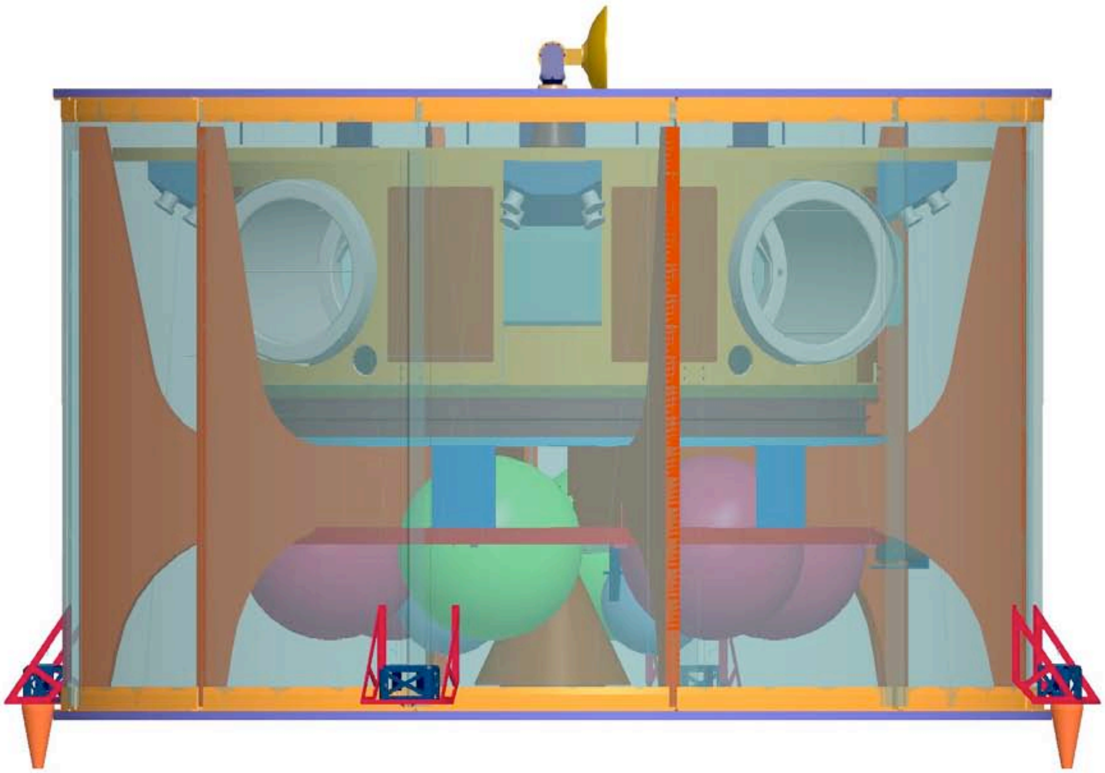


Figure 1.1: Sciencecraft Integrated Propulsion Module

Table 1.1-1: Propulsion Module Baseline Mission Design Parameters

Parameter	Value or Definition	Comment
Orbit Transfer Duration	15 months	Propulsion module must safely deliver the Sciencecraft to the operational orbit within this time period
Total Impulse capacity	1139m/s	Total delta V requirement based on worst case LCM transfer plus margins
Attitude & orbit control	Provide attitude and orbit control during the transfer period	P/M must include provision for altering attitude and orbit throughout the transfer period

Communication	Low-rate (variable – minimum 50 bps) communication with GS throughout the transfer	Propulsion module must provide attitude-independent telecommunication capability at a minimum data rate throughout the cruise phase
SC & Payload Temperature	All SC/Payload and P/M elements to be maintained with acceptable temperature boundaries (room temp.)	The propulsion module will facilitate preferably passive maintenance of acceptable temperatures for all elements of the payload and SC throughout the cruise phase
Attitude sensing	TBD arcsec RMS 3σ TBR	Ensure sufficient sensing accuracy during cruise phase
Payload Contamination	Payload cleanliness of TBD to be maintained throughout the transfer	The propulsion module must protect the payload from contamination throughout the pre-launch, launch, LEOP and cruise phases, and also avoid introducing contaminants upon separation
Payload Venting	Payload cavity pressure must be 1*10E-6 Pascals upon commencement of the commissioning phase	Propulsion module must facilitate venting from the payload to the required pressure per Atlas V ascent profile.
Separation & Retire	Achieve SC insertion accuracy of TBD m/s and retire from SC at TBD m/s	Propulsion module must safely separate from the Sciencecraft and retire to a safe distance at the end of the cruise phase

Parameter	Value or Definition	Comment
Lifetime	18 month cruise phase	14 months for transfer trajectory + 4 months commissioning
Reliability	Design must be Class B compliant	Single fault tolerant
Contamination	Thruster plumes must not impinge on or contaminate the payload.	
System Design	Bus is built around the Payload, Sciencecraft nests in Propulsion Module (PM), 3 S/C are stacked in the fairing with the P/M carrying the majority of the launch loads	
AIT	Design must accommodate full accessibility to key components during all Assembly, Integration and Test (AIT) activities.	
P/M Separation Relative Velocity	5.0 ± 1.0 cm/sec	
P/M Separation Tip-off Rate	2.0 ± 0.2 deg/sec	P/M to P/M separation
P/M Separation Shock	400 g max.	

1.1.1 PM Mechanical System Overview

The three primary functions of the Propulsion Module Mechanical System are to:

1. Transport the Sciencecraft from Launch & Early Orbit Phase (LEOP) to final orbit insertion
2. Provide structural support and a protective environment for the Sciencecraft throughout LEOP and the 18 month cruise phase
3. Provide a platform for deployment of each individual Sciencecraft during orbital insertion operations

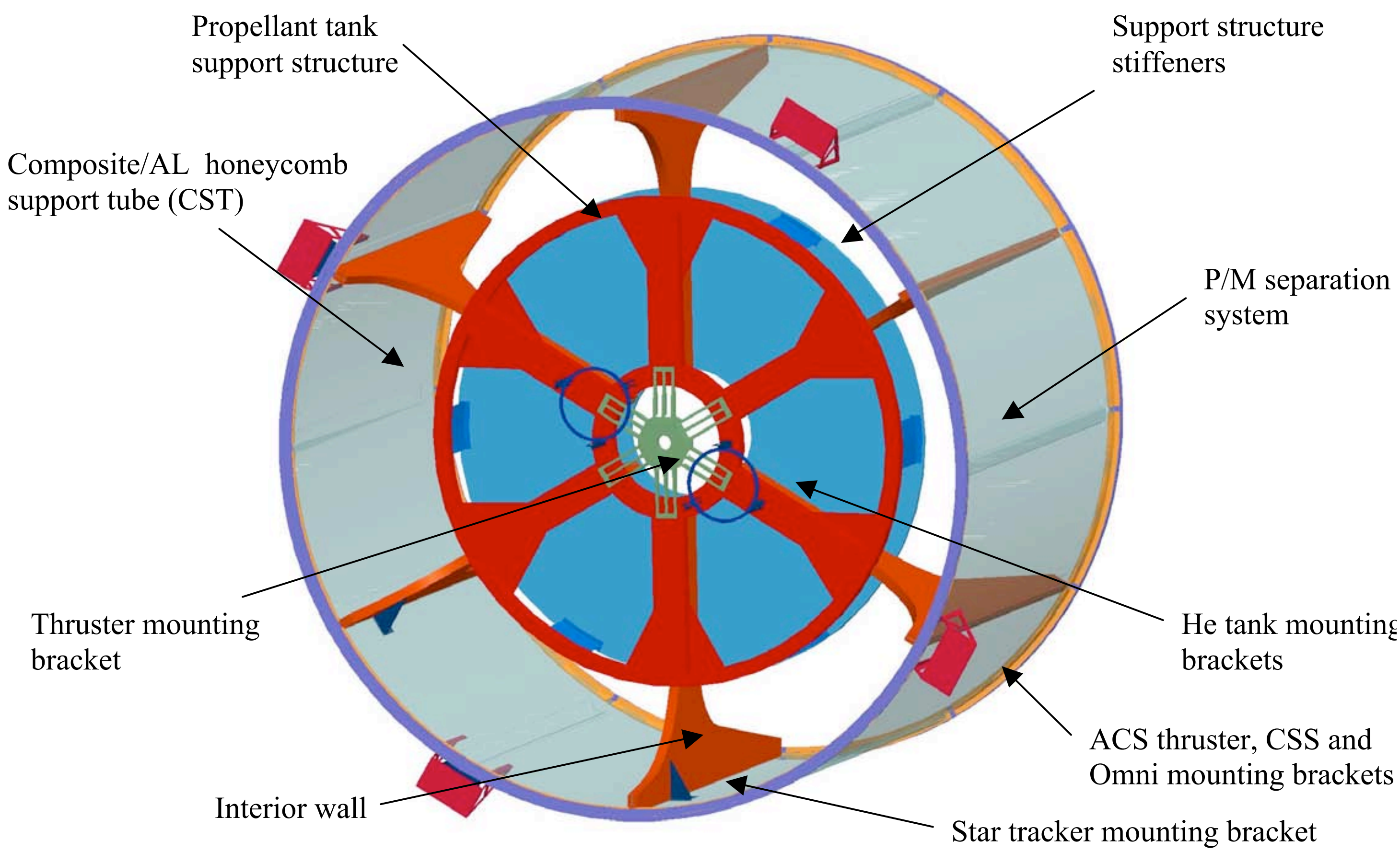
An annular separation system will attach the bottom deck of the Sciencecraft to the top deck of the P/M. This design will provide the required system stiffness and will allow the Sciencecraft launch loads to be transferred through the P/M interior structure and then into the Composite Support Tube (CST). The P/M's will stack on top of each other with the bottom most P/M attached to a PAF launch vehicle interface. Separation systems similar to the Sciencecraft separation system will attach to the CST and will separate each of the Prop. Module/ Sciencecraft integrated assemblies from each other and from the PAF during LEOP. The design intent behind the Propulsion Module/Sciencecraft integrated assembly stack is to provide the required stiffness in the most efficient manner possible.

Besides being a structurally efficient design, the CST will also provide a protective barrier for the Sciencecraft payload. The protective barrier offered by the CST eliminates the need for protective covers over the optically sensitive components, i.e. telescope primary and secondary mirrors, Star Trackers and other components that could be contaminated during AIT activities or by orbital debris during LEOP or damaged by direct sun light impingement during the LEOP and cruise phases.

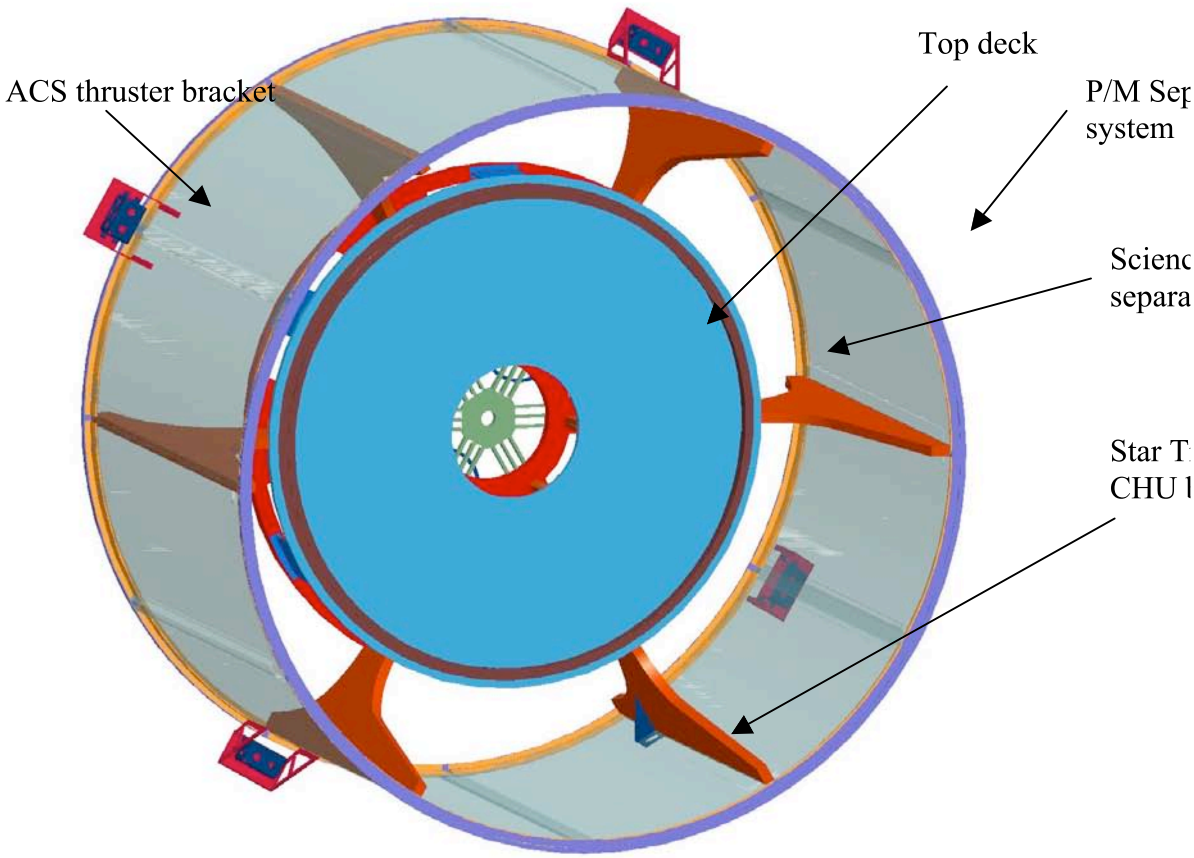
At the core of the P/M Mechanical System lies a composite base structure comprised of the CST, interior walls, a top deck panel that supports the Sciencecraft and a lower support structure that supports the propellant tanks. The built-up mechanical system consists of the base structure, two P/M separation systems, the Sciencecraft separation system, a mounting bracket for the main LAE thruster, mounting brackets for the He tanks, brackets on the exterior for ACS thrusters and sun sensors, brackets for Star Tracker Camera Head Units, and brackets for omni antennas.

C&DH functions for the Propulsion System, Comm. System and ACS onboard the P/M will be provided by the Sciencecraft C&DH System. Electrical power for the P/M will also be provided by the Sciencecraft. Command signals and power from the Sciencecraft will be delivered to the P/M through a zero insertion force connector in the separation system.

An illustration of the P/M Mechanical System built up assembly is provided in Figure 1.1-1. Dimensioned views of the P/M are provided in Figure 1.1-2.

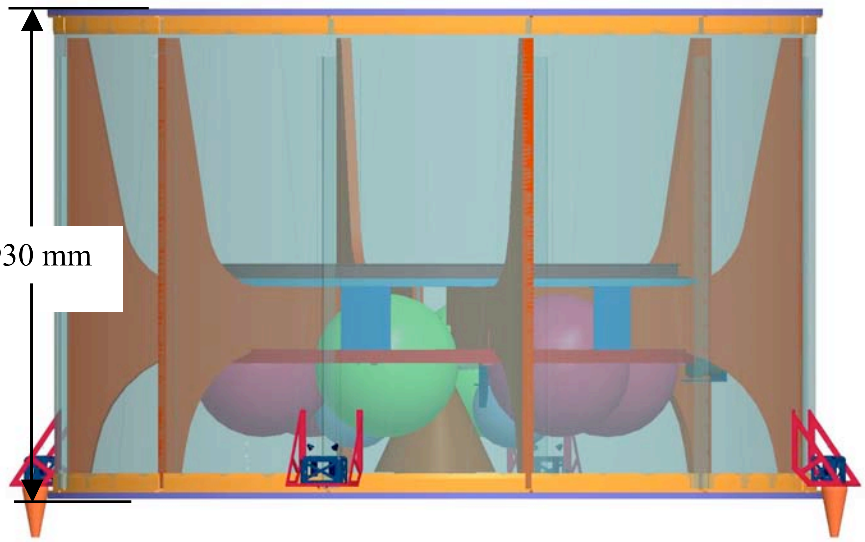


Bottom View

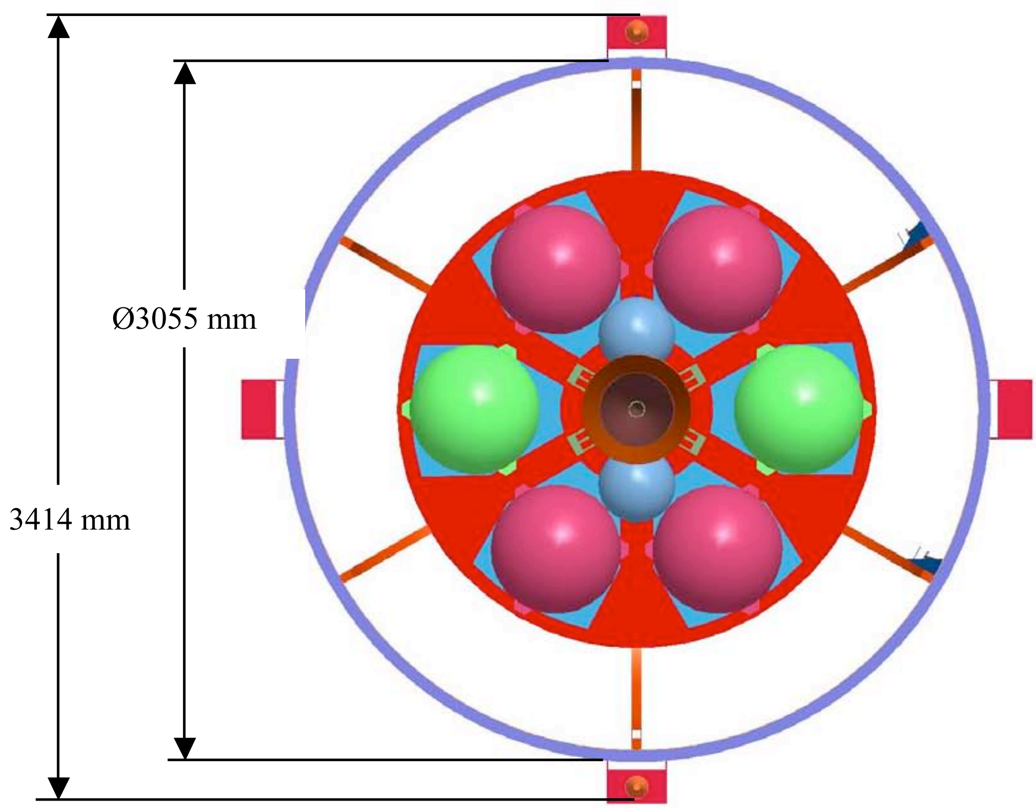


Top View

Figure 1.1-1: Propulsion Module Mechanical System



Side View



Top View

Figure 1.1-2: Propulsion Module Dimensions

1.1.2 P/M Mechanical System Architecture

A schematic block diagram showing the major components and interfaces of the P/M Mechanical System is shown in Figure 1.1-3

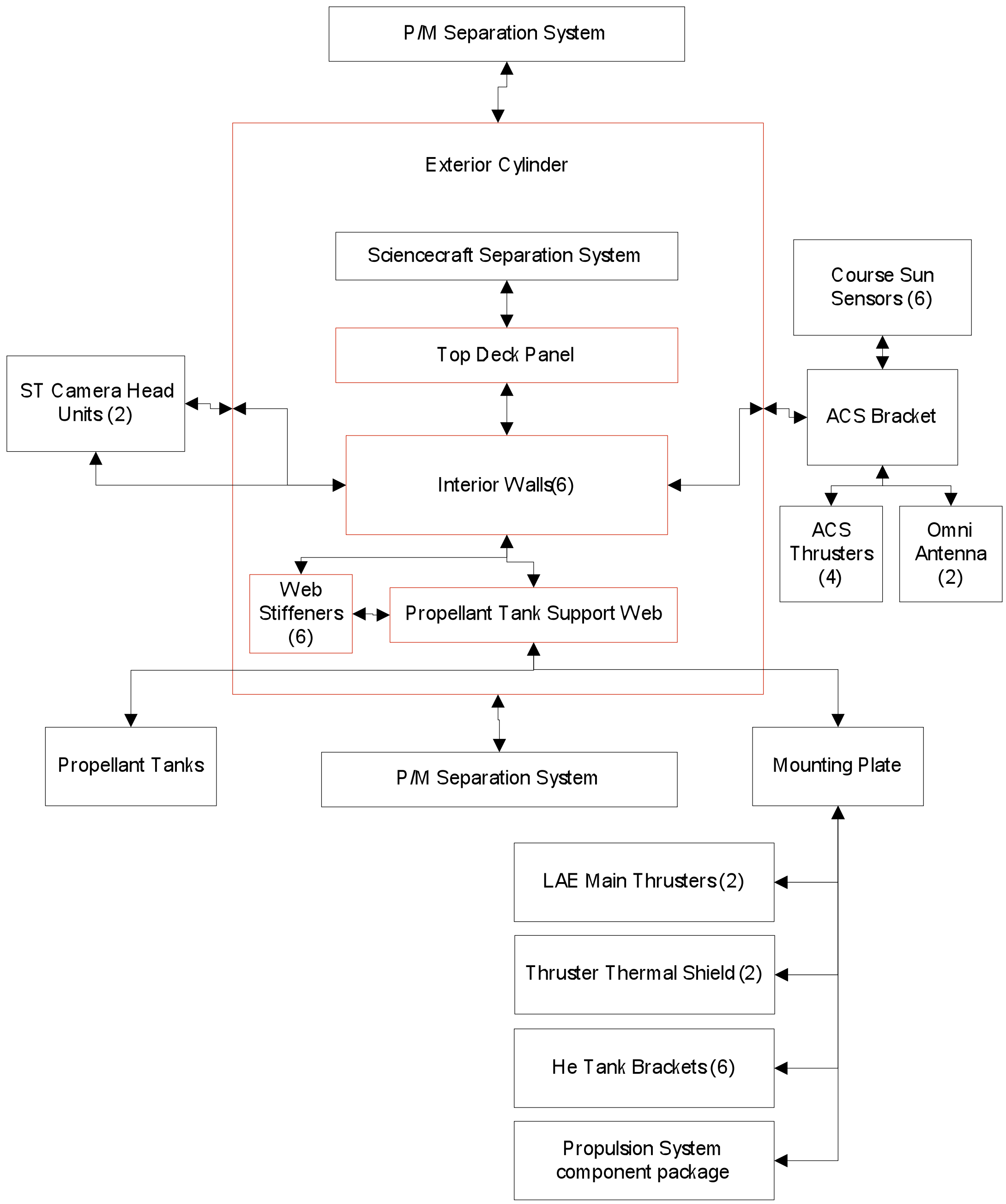


Figure 1.1-3: P/M Mechanical System Interface Diagram

1.1.2.1 P/M BASE STRUCTURE

The P/M base structure consists of the CST, the interior walls, the propellant tank support structure with stiffeners and the top deck panel. The top deck panel, CST and interior walls will be made of composite honeycomb panel of various thicknesses. The propellant tank support structure will be made of square composite tube. The base structure components will be joined together with adhesive bonded double lap joints. The P/M base structure is shown in Figure 1.1-4.

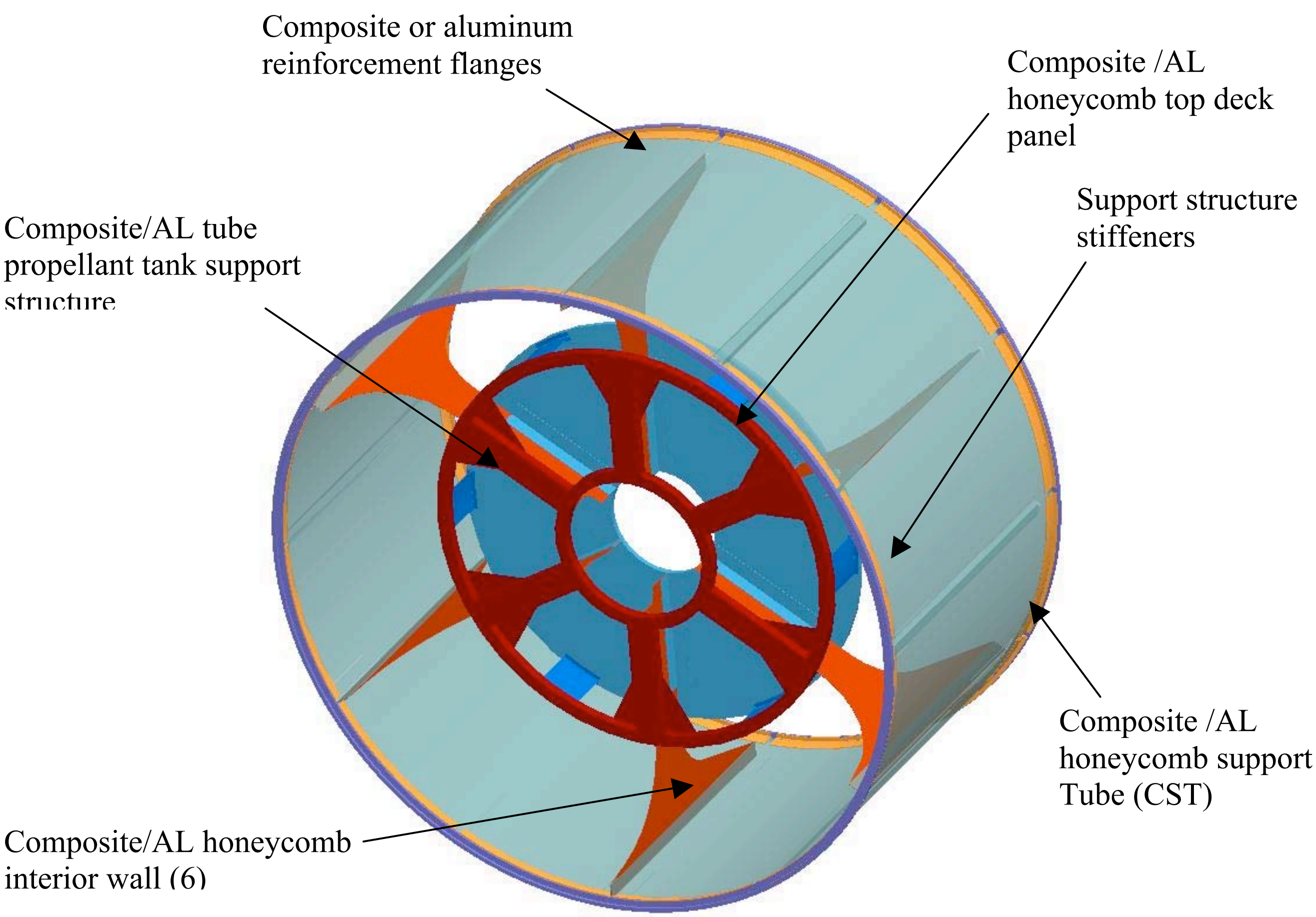


Figure 1.1-4: P/M Base Structure

1.1.2.2 PROPULSION MODULE SEPARATION SYSTEM

Separation systems are required for two stages of separation during the LISA mission. The first stage is the separation of each individual S/C integrated assembly from the launch vehicle. This operation will occur in a serial fashion, i.e. with the upper most S/C separation occurring first and the separation of the bottom most S/C from the launch vehicle PAF occurring last. The second stage occurs during orbital insertion following the 14 month cruise phase whereby the Sciencecraft separates from the Propulsion Module.

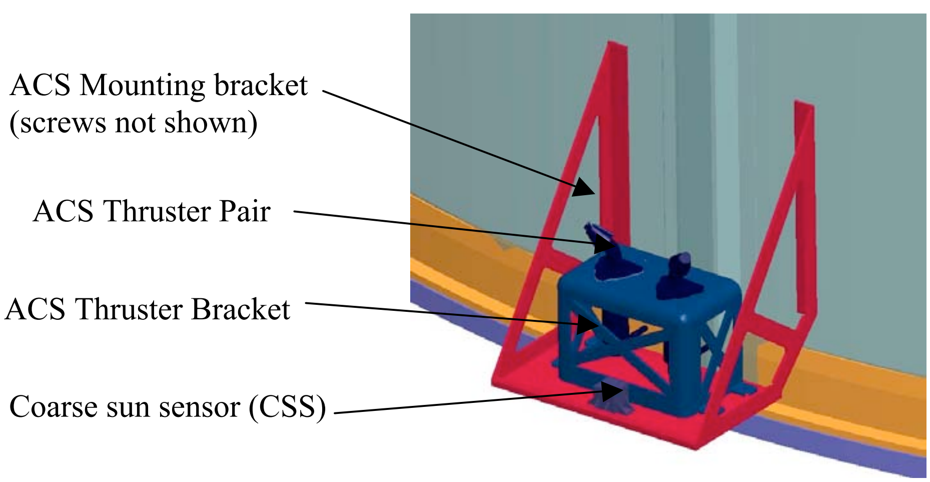
The Propulsion Module separation system must be capable of separating the S/C integrated assemblies with a relative velocity of 5.0±1.0 cm/sec and a tip-off rate less than 2.0± 0.2 deg/sec. Separation shock must not exceed 400g.

The baseline design will employ a Motorized Lightband (MLB) separation system made by Planetary Systems Corp. The advantage that the MLB has over conventional separation systems is the fact that the release mechanism uses an electric motor that can be reset quickly while conventional pyrotechnic release systems require a significant amount of time to reset the system. Besides the advantage this design would have during AIT activities, the MLB is also lighter in weight than a conventional separation clamp band and it produces significantly less shock during separation.

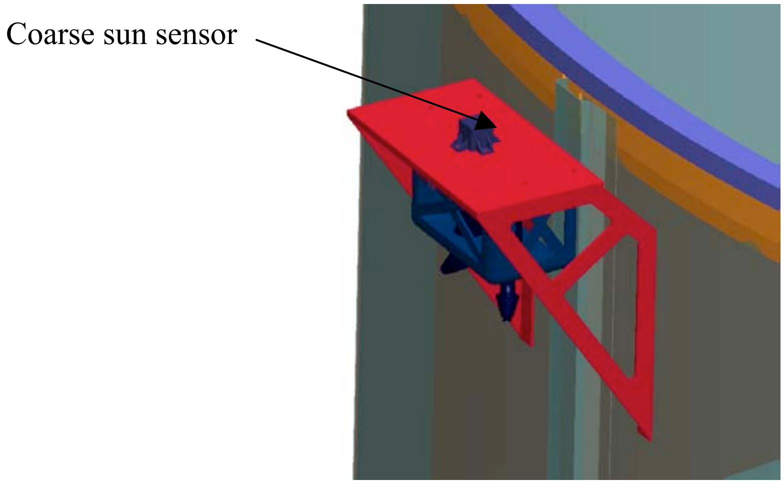
The P/M separation systems will be bolted to mating flanges on the top and bottom of the CST as shown in Figure 1.1-1.

1.1.2.3 ACS ACCOMMODATIONS

The Propulsion Module Mechanical System must provide mounting interfaces for ACS thrusters, Coarse Sun Sensors (CSS's) and Star Tracker Camera Head Units (CHUs). Brackets for mounting four pairs of ACS thrusters will be positioned at 90 degree intervals around the outside of the CST. The ACS thruster brackets will also provide attachment interfaces for four CSS's on the top side of the ACS mounting bracket adjacent to the ACS thrusters in all 4 locations, and on the bottom surface of the ACS bracket in two locations. Figure 1.1-5 shows the mounting design for the ACS thrusters and CSS's.



Top Side View of ACS Thruster and CSS Mounting (4 Places)



Bottom Side View of ACS Thruster and CSS Mounting (2 Places)

Figure 1.1-5: ACS Thruster and CSS Mounting

During the LEOP and cruise phases of the mission, the ACS will rely on Star Trackers in addition to the sun sensors for absolute attitude sensing. The P/M CST blocks the view of the Star Tracker Camera Head Units (CHUs) onboard the Sciencecraft, thus requiring the placement of two additional CHU's mounted on the CST. The mounting locations on the CST were chosen to provide a view of space that would be minimally affected by thruster plumes during the cruise phase. An angular spacing of 60 degrees between the CHU's was chosen to provide overlapping FOVs to provide hot redundant attitude sensing data. Brackets will mount the CHU's to to the CST as shown in Figure 1.2-5.

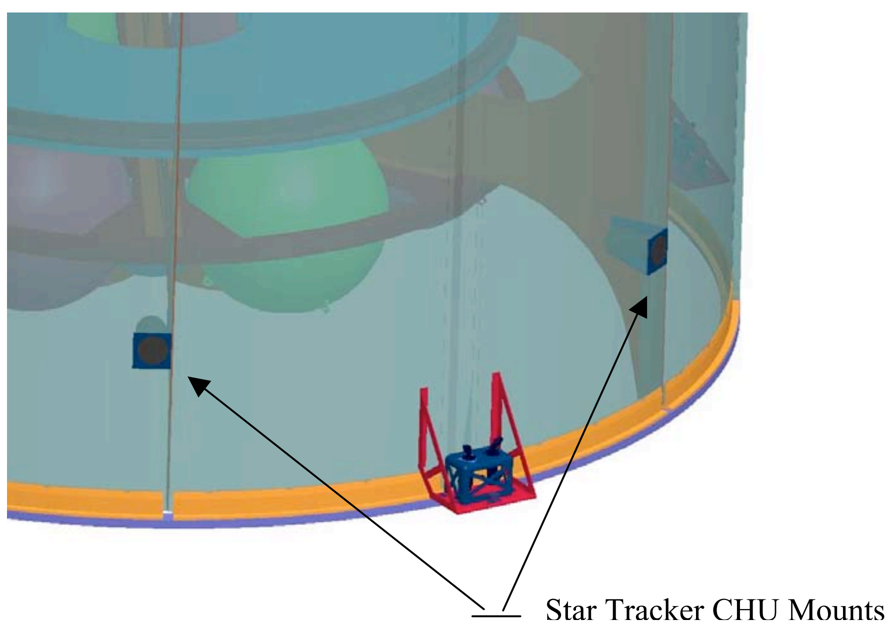


Figure 1.1-5: Star Tracker Camera Head Unit Mounting

1.1.2.4 PROPELLANT TANK SUPPORT STRUCTURE

A composite tube support structure will be attached on the bottom of the interior walls using adhesive bonded double lap joints. The design intent behind the support structure is to efficiently distribute the propellant load evenly around the center of the P/M during launch and thrust maneuvers and to transfer that load to the CST through the interior walls. Symmetrically configuring the four propellant and two oxidizer tanks into six equally sized spheres makes this design possible. This design minimizes axial CG migration away from the spacecraft centerline as the propellant and oxidizer are consumed. The propellant tank mounting design is shown in figure 1.1-6.

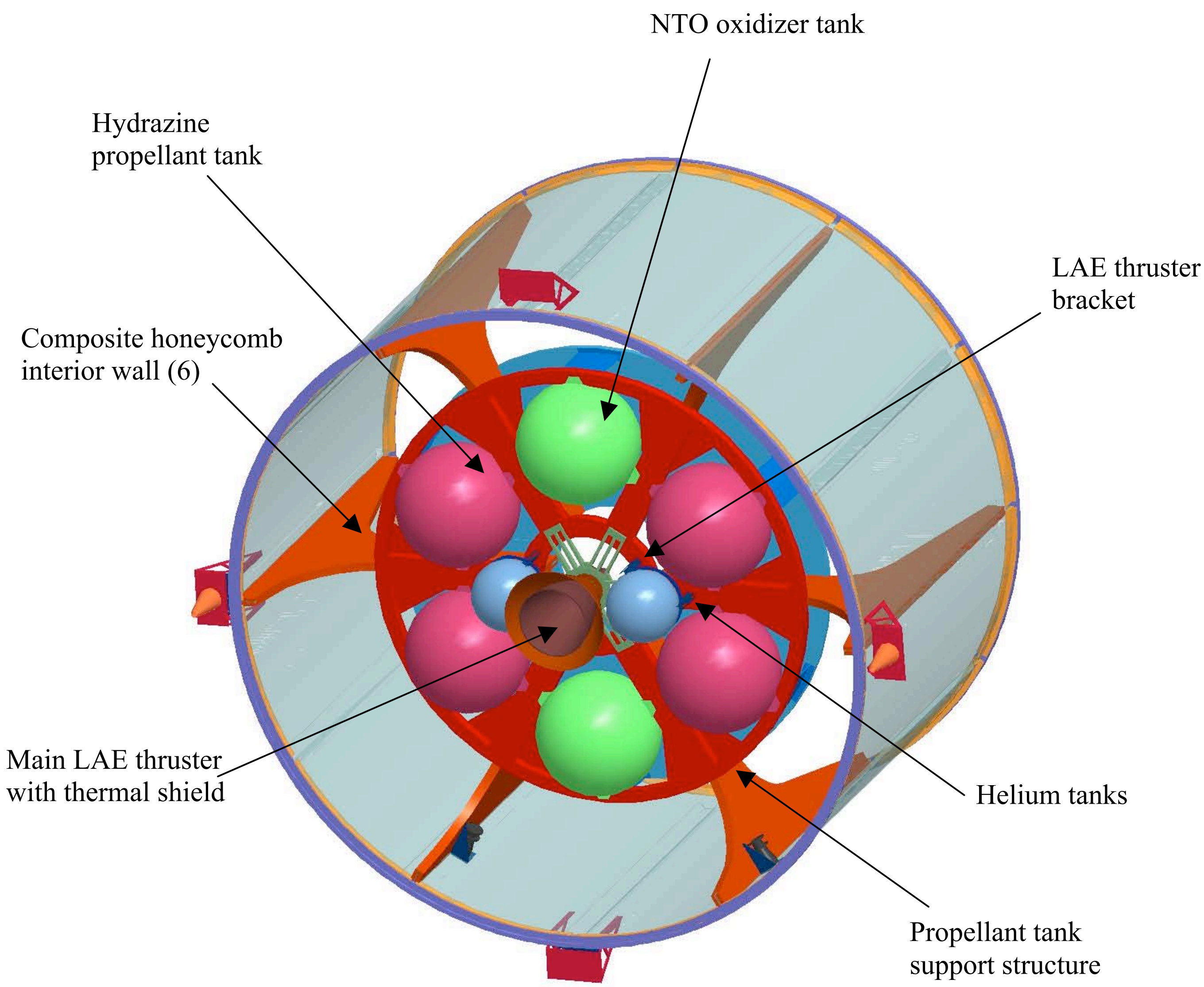


Figure 1.1-6: Propellant Tank Support Structure

1.1.2.5 LAE THRUSTER AND HE TANK MOUNTING

Beneath the propellant tank support structure, a bracket will be provided for mounting the main LAE thruster. Available areas on the top and bottom surfaces of the bracket will also be used for mounting various propulsion system components such as latch valves, pressure transducers and pyro-valves. The bracket will be made from machined lightweighted aluminum plate, aluminum honeycomb, or composite honeycomb with the required interfaces for hardware mounting. Each helium tank will be supported by three mounting legs fastened to pre-defined structural tabs on the tank. The helium tank mounting brackets will bolt directly to the propellant tank support structure as shown. The LAE thruster and Helium tank mounting designs are shown in Figure 1.1-7

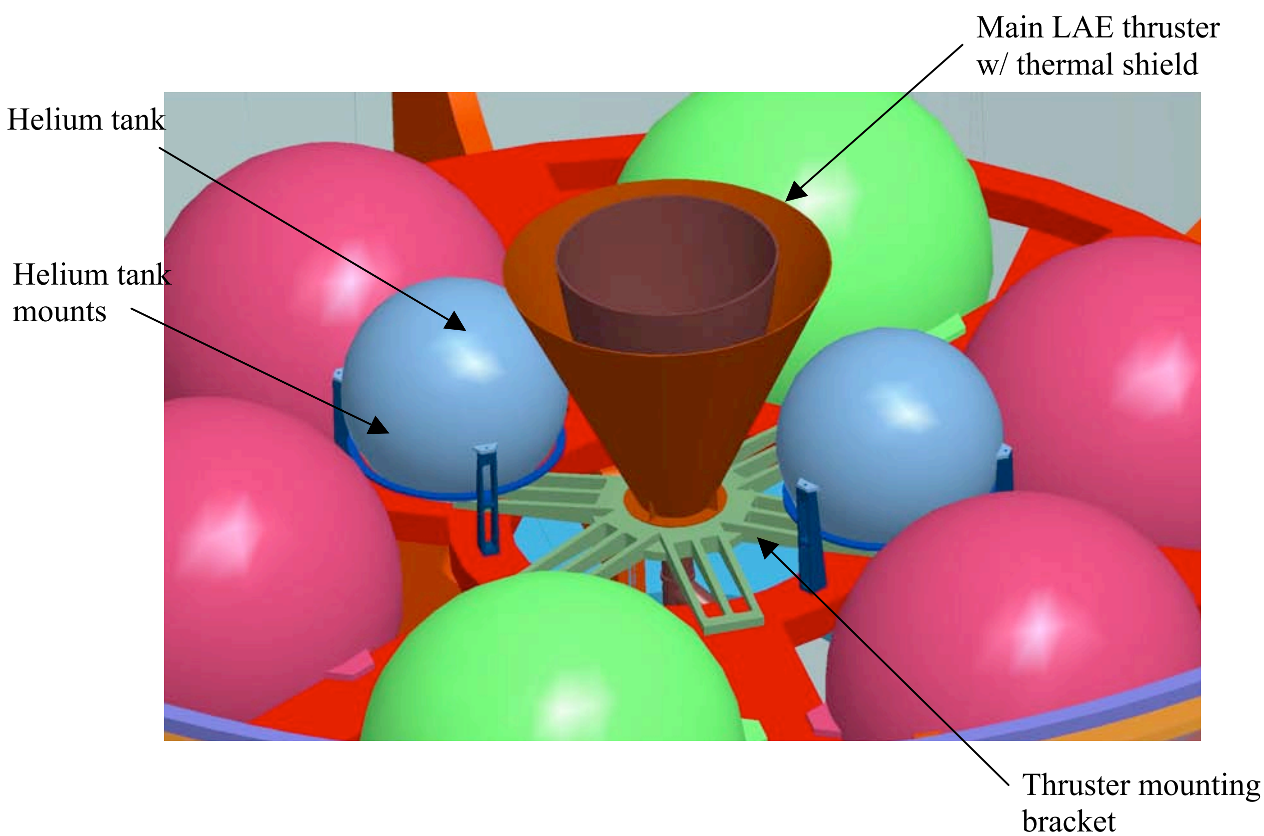


Figure 1.1-7: LAE Thruster and He Tank Mounting

1.1.2.6 OMNI ANTENNA MOUNTING

Two omni antennas will be mounted on the underside of the brackets holding the ACS thrusters and CSS's. The omni antenna mounts are shown in Figure 1.1-8.

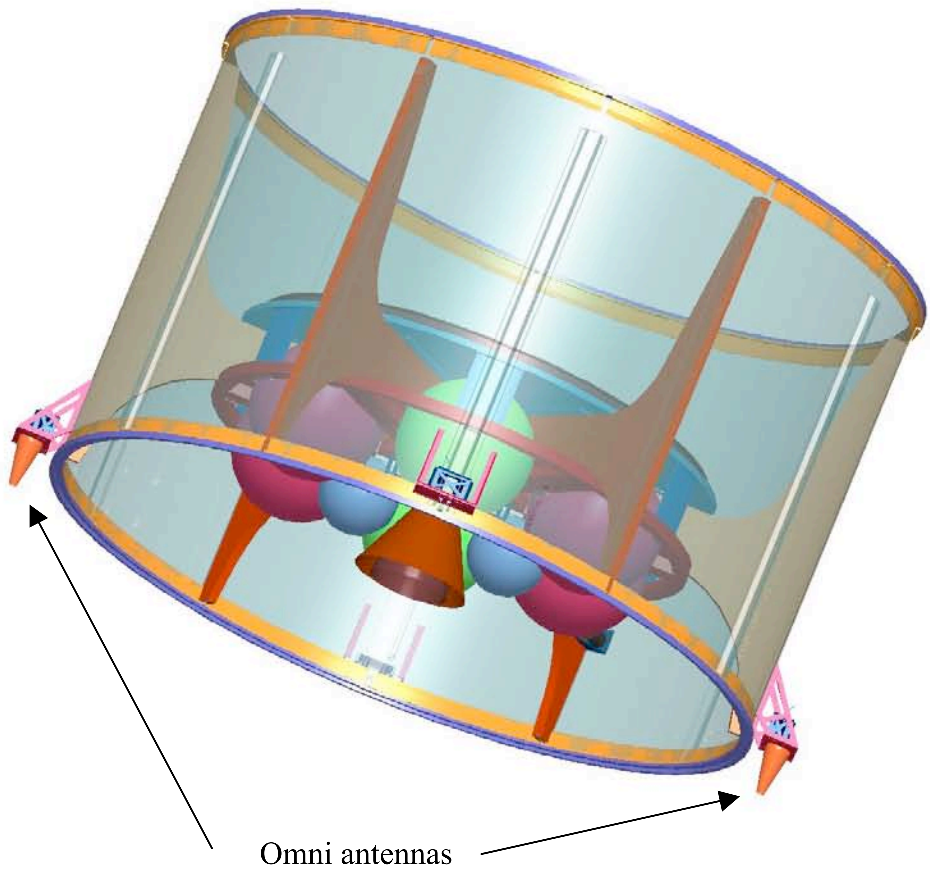


Figure 1.1-8: Omni Antenna Mounts

1.1.3 SCIENCECRAFT SEAL INTERFACE

The cleanliness requirements of the payload will require that the Sciencecraft be fully encapsulated by the P/M CST and therefore protected from the launch environment. A gap that is approximately 10cm in size between the SC solar array deck and the PM CST constitutes an annulus that exposes the SC structure and payload of the top Sciencecraft in the launch stack to the wider environment of the fairing. This exposure applies to the top most Sciencecraft as the bottom two Sciencecrafts are completely sealed from the fairing environment by virtue of the mated PM sitting above them. A circular seal placed between the bottom outer edge of the Sciencecraft solor array deck and a flange on the PM CST interior will be used to provide an enclosed and clean environment for the Sciencecraft once final integration with the PM has taken place.

Venting will become necessary during the assent phase of launch due to entrapped air inherent in the system. Vents located on the PM CST will allow for venting the PL inside the Bus to ensure a pressure lower than 10^{-5} Pa in the GRS. Also, vent pathways will be chosen so as to prevent cryo-pumping in the most sensitive areas of the Sciencecraft, e.g. the telescope primary-secondary mirror volumes. A preliminary analysis has been performed extrapolating the overall quantities of the material constituting the P/M and Bus. The results shown in Figure 1.1-9 show that a good pressure environment is reached within the time needed for the transfer phase (i.e. about 300 days).

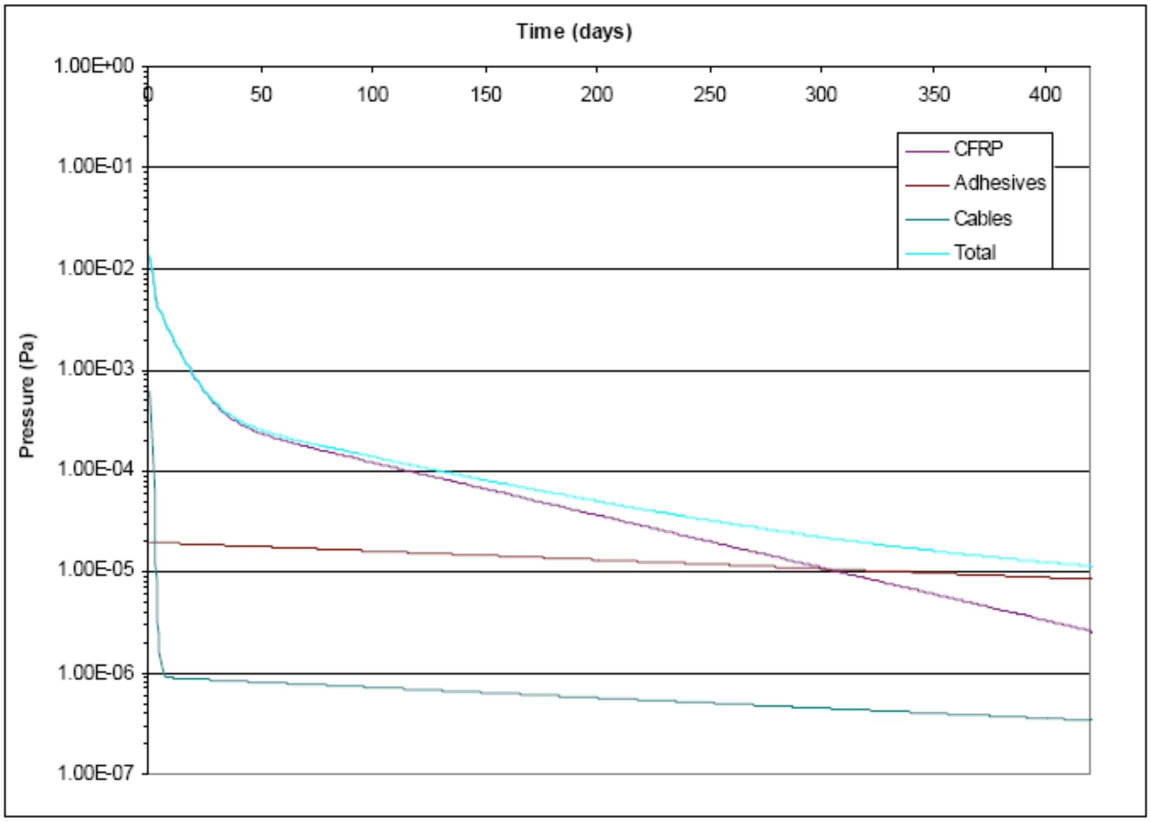


Figure 1.1-9: Pressure Decay

1.1.4 P/M Mechanical System Design Alternatives

1.1.4.1 Alternative Separation System

A SAAB Aerospace separation system is an alternative to the baseline P/M separation system. SAAB separation systems have a record of high reliability with a 100% success rate for more than 350 in-orbit separations between 1981 and 2007. However the release mechanism in the SAAB system relies on pyrotechnic actuation. Resetting the system during AIT activities will likely require replacing the entire pin-puller mechanism which could significantly impact schedule and cost. A diagram illustrating how the SAAB separation system works can be found in the Sciencecraft Description Document.

1.1.4.2 SCIENCECRAFT STAR TRACKER VIEWING PORT

A viewing port in the P/M shell that would provide the Sciencecraft Star Tracker CHU's with a view of space during the cruise phase would eliminate the necessity of having two additional CHU's installed on the P/M shell. Analysis is currently under way to determine if such viewing ports could be integrated into the P/M shell.

1.1.5 HARDWARE SUMMARY

Table 1.1-2 provides a P/M Mechanical System hardware summary. The components and performance specs listed below represent candidate hardware that might be used in the final LISA P/M Mechanical System design. Hardware information accuracy will improve as the Mechanical System design matures.

Table 1.1-2: P/M Mechanical System Hardware Summary

Component	Supplier	Model	Qty
Separation System	Planetary Systems Corp.	TBD	1
Separation System (alt.)	SAAB Aerospace	TBD	1

1.1.5.1 PLANETARY SYSTEMS SEPARATION SYSTEM

Motorized Lightband (MLB) model number 66.000-104 made by Planetary Systems Corp., which is the baseline separation system for the Sciencecraft, represents a separation system similar to the baseline P/M separation system. The P/M separation system will be a larger scale variant of the Sciencecraft system. Illustrations, dimensional information and performance specs for the MLB system are provided in the Sciencecraft Description Document.

1.1.5.2 SAAB AEROSPACE SEPARATION SYSTEM

SAAB Aerospace separation system model 1666VS, which is the alternative separation system for the Sciencecraft, represents a smaller scale separation system similar to the alternative P/M separation system. The SAAB Aerospace separation system is shown in the Sciencecraft Description Document.

1.2 P/M Propulsion System Design

Mission baseline parameters driving the LISA Propulsion System design are referenced in Table 1.2-1.

Table 1.2-1: Propulsion System Baseline Parameters

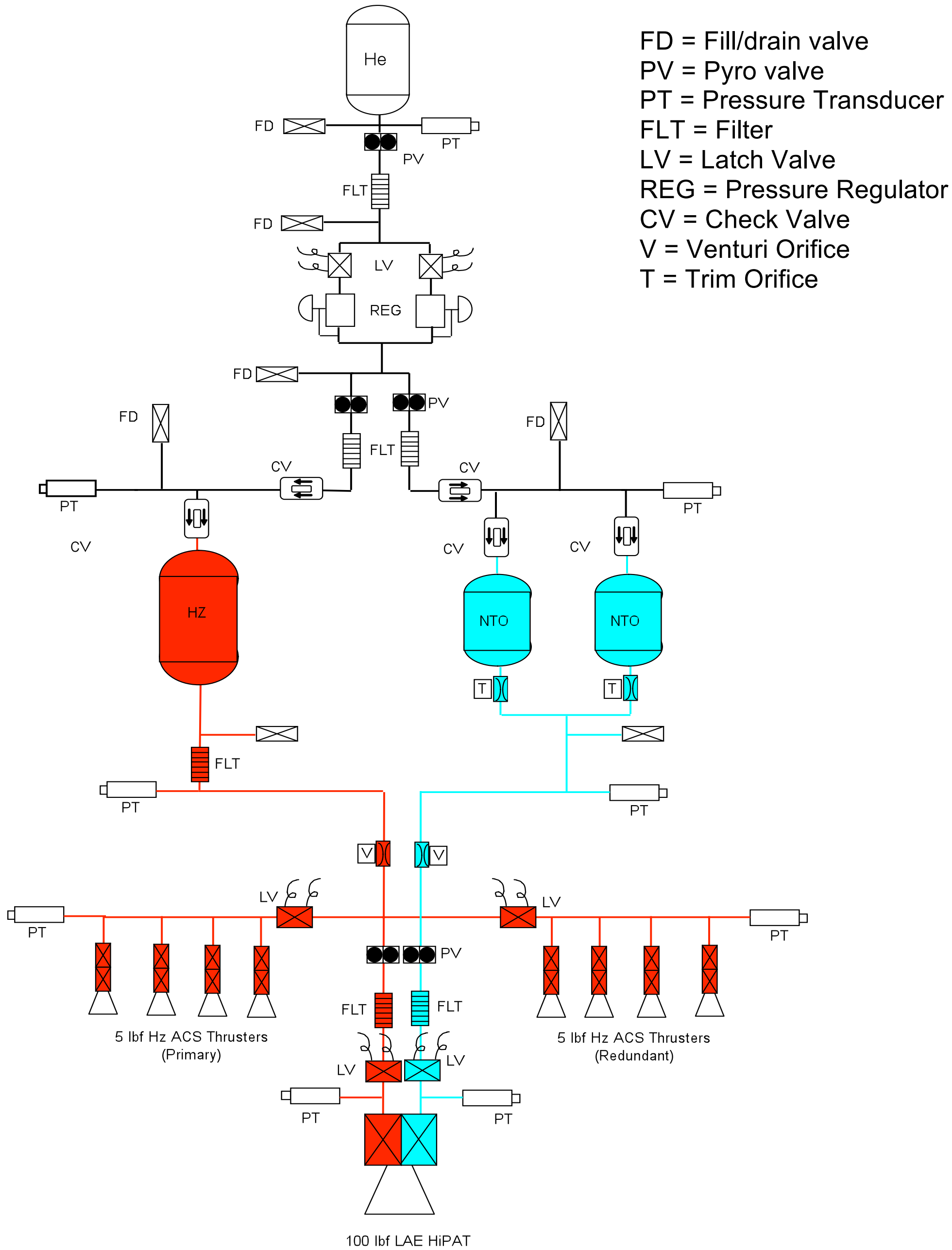
Parameter	Comments
Cruise Phase Duration	14 months for transfer trajectory + 4 months commissioning
Orbits	3 independent, Heliocentric, 20° earth trailing orbits, equilateral triangular constellation with 5 x 10^6 km +/- 1% arm lengths, constellation requires no active station keeping or maintenance over the mission lifetime
Reliability	Design must be Class B compliant (single fault tolerant)
Contamination	Thruster plumes must not impinge on or contaminate the payload
Required ΔV	1130 m/s

1.2.1 P/M Propulsion System Overview

The propulsion system is responsible for transferring the S/C from LEOP to science orbit within the 18 month cruise phase. Once the S/C is positioned into science orbit, ACS thrusters will orient the Sciencecraft to the 30 degree angle of incidence to the sun. The ACS thrusters will then impart a spin upon the S/C to give the Sciencecraft axial stability during separation. The function of the propulsion system ends once the Sciencecraft is deployed. The propulsion system baseline design is a dual mode system that employs a single bi-prop Liquid Apogee Engine (LAE) main thruster for ΔV thrust and a dual string array of mono-prop ACS thrusters. The baseline design is Class B compliant even without carrying additional fuel to allow the ACS thruster substitute for the LAE. While the LAE is a single mechanical design, it is deemed non-credible due to the dual coil LAE valves, which are single fault tolerant. The propulsion system will interface with C&DH and EPS systems onboard the Sciencecraft via an umbilical connection across the separation plane. This propulsion system is an entity separate from the Micro-Newton thrusters used by the DRS onboard the S/C.

1.2.2 P/M Propulsion System Architecture

The baseline propulsion system is a dual mode bi-propellant design featuring a main thruster powered by Hydrazine (Hz) propellant and Nitrogen Tetroxide (NTO) oxidizer and an array of Hz powered ACS thrusters. Helium pressurant will be used to maintain the propellant system pressures. The propellant tanks and thrusters will be connected by a system of rigid titanium and stainless steel tubing and an array of fluid control devices. Redundant flow paths and redundancies built into the fluid control devices make the baseline design single fault tolerant. A schematic of the propulsion system is provided in Figure 1.2-1.



Source: MDL Jan 08

Figure 1.2-1: Propulsion System Schematic

1.2.2.1 PROPELLANT TANKS

Helium, hydrazine and NTO will be stored in Titanium tanks mounted to the P/M structure. The baseline design calls for a single He tank, a single Hz tank, and two NTO tanks. Packaging constraints may require redistributing the propellant into a larger number of smaller tanks. Whatever the configuration, the propellant tanks will have to be placed such that the S/C cg remains centered on the thrust axis as the fuel and oxidizer are consumed. The propellant tank layout shown in Figure 1.2-2 is one of many possible configurations.

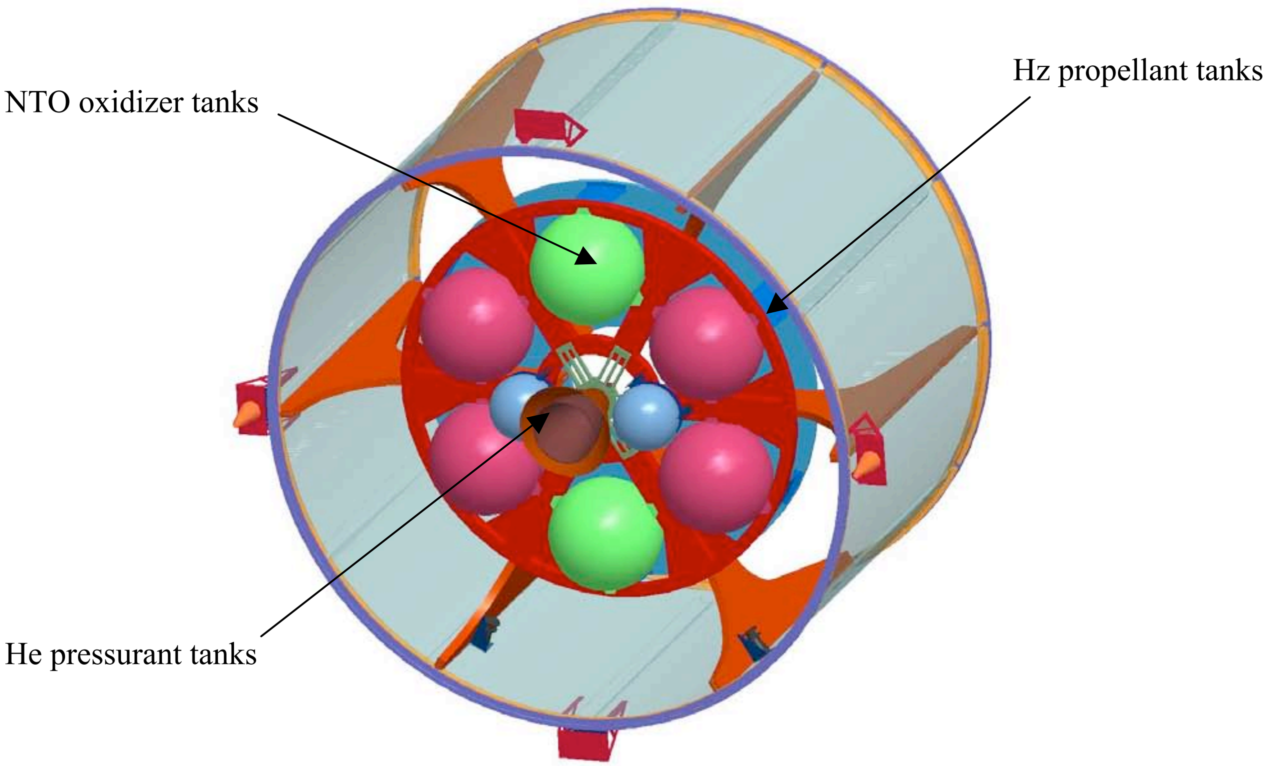


Figure 1.2-2: Fuel Tank Installation

A requirement to carry a He pressurant volume of 4,105 in^3 with a Maximum Expected Operating Pressure (MEOP) of 4,500 psia is based on the required propellant load and propellant operating pressures required by the thrusters to meet the ΔV requirement. Parameters governing pressurant tank sizing are listed in Table 1.2-2.

Table 1.2-2: He Pressurant Tank Sizing Parameters

LISA He Tank Sizing Analysis	
$V_{NTO\ TK}$ (in^3) =	11,250
$V_{Hz\ TK}$ (in^3) =	18,817
$V_{He\ TK}$ (in^3) = PSI COPV 80400-1	4,105
T_{min} (R) =	510
T_{max} (R) =	570
Minimum P_{Reg} Inlet Pressure (psia) =	360
MEOP P_{He} (psia) =	4,500
EOL P_{He} (psia) =	484.0
Number of He Tanks	1
He Tank Mass (lbm) =	22

Source: MDL Jan 08

A single Hz tank design would be limited to placing the Hz tank on the S/C centerline due to flight dynamics constraints. Configuration options using multiple Hz tanks would have the Hz tanks mounted symmetrically around the S/C centerline. The NTO tanks would also be mounted symmetrically from the S/C centerline where packaging constraints permit. The hydrazine and NTO tank sizes are driven by the dry mass of the S/C, ΔV requirements, LAE mixture ratio and cosine factors based on thruster orientation. The propellant tanks will be modified for a 0.97 fill fraction. Since all S/C accelerations will point along the ΔV axis a "star basket" type Propellant Management Device can be used to minimize tank mass. Table 1.2-3 provides the propellant tank sizing parameters.

Table 1.2-3: Propellant Tank Sizing Parameters

LISA NTO/Hz Tank Sizing Analysis		
Propellant	Hz	NTO
Mass (lb_m)	628.3	534.1
Maximum Design T_{max} (°F)	110	110
Nominal Operating T_{op} (°F)	70	70
Densities @ T_{max} (lb_m/ft^3)	61.62	86.92
Densities @ T_{op} (lbm/ft3)	62.88	90.07
Propellant Volumes @ T_{max} (in^3)	17,620	10,618
Propellant Volumes @ T_{op} (in^3)	17,269	10,246
Blowdown Ratio	1.00	1.00
Number of Tanks	1	2
Propellant Volume/tank @ T_{max} (in^3)	18,149	5,468
Actual Tank Volumes (in^3)	18,817	5,625
Tank MEOP (psia)	300	300
Actual BOL Pressure @T_{op} (psia)	235	235
Actual EOL Pressure @T_{op} (psia)	235	235
Actual Blowdown Ratio	1.00	1.00
Fill Fraction @ T_{max}	0.936	0.944
Fill Fraction @ T_{op}	0.918	0.911
Tank Pressure @ T_{max} (psia)	83.5	143.5
Tank Mass (lbm)	30	15
Tank Part No.	80405-1 Modified PMD	Custom Tank Qual Required
Tank Geometry	21.25" ID x 61.74 Long	TBD
Vapor Pressure @ T_{max}	0	38.6
Vapor Pressure @ T_{op}	0	14.5

Source: MDL Jan 08

1.2.2.2 THRUSTERS

The baseline dual mode propulsion system uses a single 445N (100 lb_f) Hz/NTO LAE for primary thrust, and eight 22N (5 lb_f) Hz mono-prop ACS thrusters canted outward at 15 degrees for roll control. The dual mode design was chosen to optimize propellant mass efficiency. As previously stated, the design good provide a backup in the event of a main LAE thruster failure if extra fuel was carried. Having a substantially lower specific impulse (Isp=235s), the ACS thrusters would not be capable of providing the required ΔV if the propellant load load was optimized for the mission relying on the LAE. However, primary thruster failure is not considered to be a credible fault since it is essentially a manifold with no moving parts, and the thruster valve uses a dual coil solenoid. Flight heritage of the baseline design can be seen in the Solar Dynamics Observatory (SDO) propulsion system configuration.

1.2.2.2.1 Main Engine

A single static mounted, 445N (100 lb_f), Hz bi-prop LAE with a 325s Isp will provide primary thrust during cruise phase orbit transfer maneuvers. The main thruster will be aligned along the S/C centerline to prevent overturning. Contamination from the thruster plume will not be a problem since the thruster will be mounted near the bottom of the P/M structure facing out towards space. The main thruster, shown in Figure 1.2-3, will require a heat shield to protect the nearby structure and fuel system hardware.

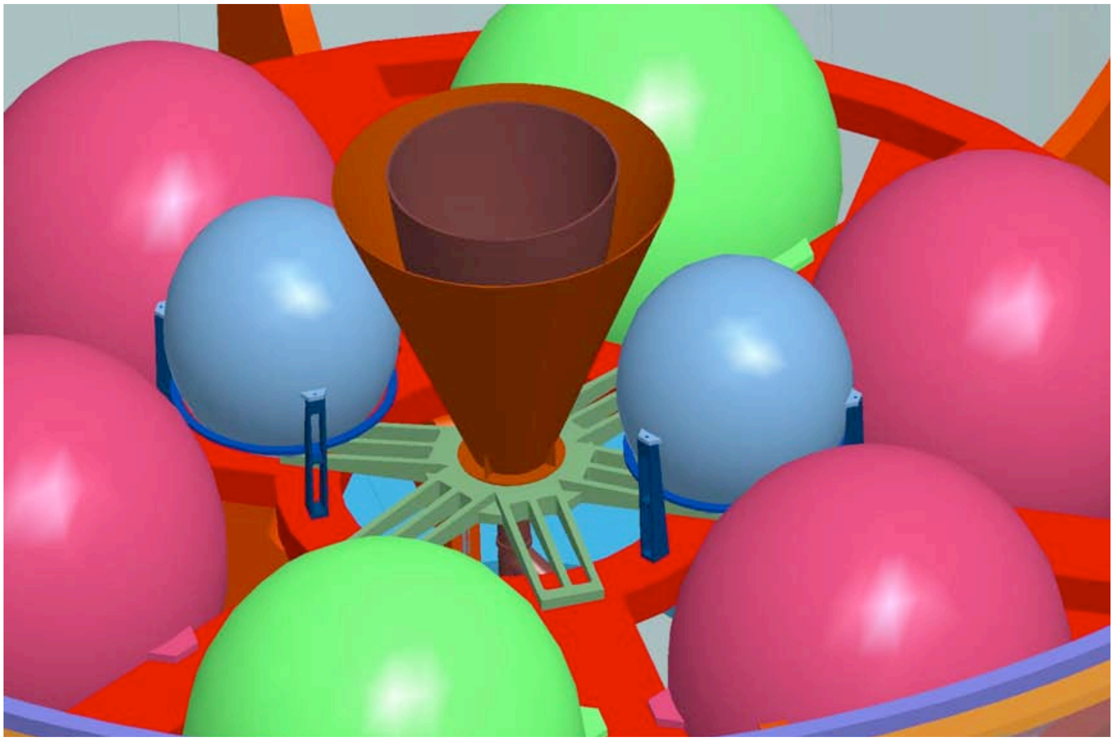


Figure 1.2-3: Main Thruster

1.2.2.2.2 ACS Thrusters

Eight 22N (5 lb_f) Hz mono-prop axial ACS thrusters with a steady state Isp of 235s (includes 15 degree cant cosine factor) will provide attitude control throughout the cruise phase. The ACS thrusters will be arranged in a dual string configuration to protect against a failed on or off thruster. Each string of four thrusters would be capable of handling the ACS duties alone should a failure occur in the other string. The ACS thrusters will be canted at 15 degrees to provide roll control and will be evenly distributed in pairs around the exterior of the P/M shell. Mounting axial ACS thrusters on the P/M exterior with a 15 degree cant angle will prevent thruster plume from contaminating sensitive optical equipment on the Sciencecraft and P/M. Mounting locations for the ACS thrusters are shown in Figure 1.2-4.

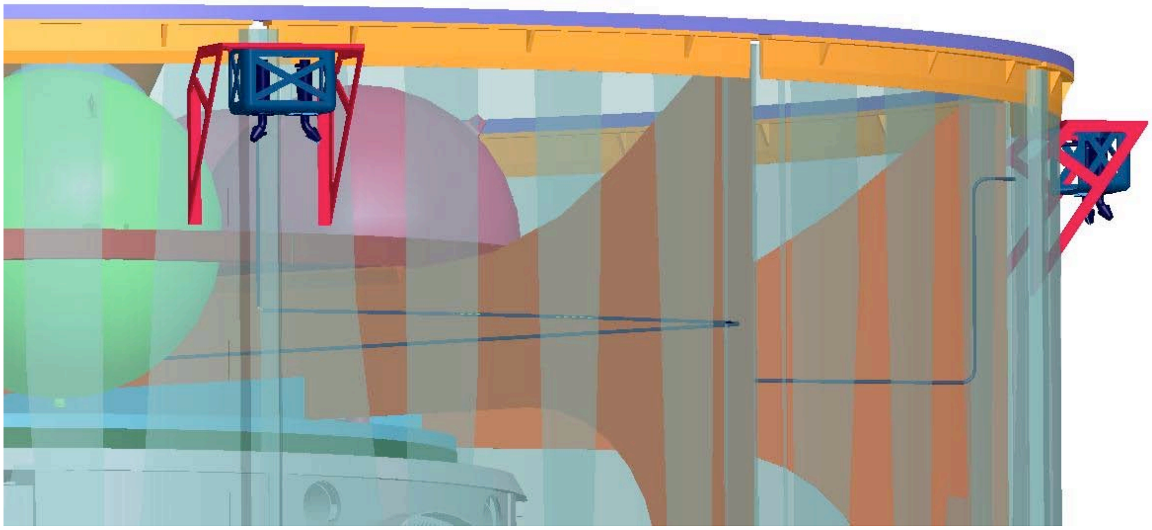


Figure 1.2-4: ACS Thrusters

1.2.2.3 PROPELLANT DELIVERY SYSTEM

The function of the propellant delivery system is to deliver hydrazine to the ACS thrusters and NTO/Hydrazine to the main engine with the proper flow rates. The propellant feed system consists of main engine Hz and NTO lines and ACS thruster hydrazine lines in a dual string configuration. The system also includes filters, isolation and service valves and pressure transducers. Class B compliance will be met using redundant flow paths and redundancies built into the fluid control devices. Heaters, thermistors and thermostats that provide thermal control critical to propulsion system operation are covered in the Thermal System section of this document

1.2.2.3.1 Helium Pressurant Line Assembly

The He pressurant line assembly is shown in schematic form connecting the Helium tank to the propellant tanks in Figure 1.3-1. The helium tank, and fluid control devices will be connected by ¼ inch rigid titanium tubing with welded connections at each interface. The Helium line assembly baseline design is shown in Figure 1.2-5.

The He line assembly uses normally closed pyrovalves to isolate the pressurant and propellant tanks during launch. Filters are located behind each pyrovalve to catch any debris from the pyrotechnic actuation, as well as any other contamination in the system. After the pyrovalves are opened, the He system begins its task of pressure regulating the propellant tanks. Pressure transducers placed near the propellant and He tanks will monitor system pressure so that the pressure regulators can control pressure supplied to the propellant tanks. The He pressure regulators are placed in parallel redundancy with in-line latch valves for fault isolation. Series redundant check valves are located near each propellant tank interface to prevent propellant back flow into the He lines. The check valves themselves are parallel redundant. Each section of the He line assembly isolated by pyrovalves must be serviced by a separate fill drain valve.

TBS

Figure 1.2-5: He Pressurant Line Assembly

1.2.2.3.2 Main Thruster Propellant Line Assembly

The main thruster propellant line assembly is shown in schematic form in Figure 1.3-1 connecting the propellant tanks to the main thruster. The propellant lines will be made of 3/8 inch rigid titanium tubing with welded connections to the propellant tanks, main thruster and fluid control devices. The main thruster propellant line assembly is shown in Figure 1.2-6.

Pyrovalves will prevent propellant from escaping out through the main thruster during launch. Filters placed behind each pyrovalve will protect the thruster from system contamination or contamination from pyrotechnic actuation. Pressure transducers located near the propellant tanks and thruster will monitor system pressure.

TBS

Figure 1.2-6: Main Thruster Propellant Line Assembly

1.2.2.3.3 ACS Thruster Propellant Line Assembly

The ACS thruster propellant line assembly is shown in schematic form in Figure 1.3-1 connecting the Hz tank to the eight ACS thrusters. The ACS thruster propellant lines will be made of ¼ inch rigid tubing made of both stainless steel and titanium. The lines connecting directly to the ACS thrusters will be stainless steel. The lines connecting the ACS thruster strings to the Hz tank will be titanium. A bi-metallic transition tube placed just downstream of each ACS thruster string isolation latch valve will connect the titanium tubing to the stainless steel tubing. Welds will connect the ACS thruster propellant lines to the ACS thrusters, the Hz tank and the fluid control devices. The ACS thruster propellant line assembly is shown in Figure 1.2-7.

A dual string configuration with latch valves will provide the ability to isolate a string if a failure occurs. The thruster strings will be configured such that attitude control maneuvers could be achieved with only one functioning string.

TBS

Figure 1.2-7: ACS Thruster Propellant Lines

1.2.3 Flight Dynamics

The propellant load required to deliver the Sciencecraft to its science orbit is determined by the estimated mass of the S/C, the specific impulse (cosine corrected) characteristics of the thrusters, and the total ΔV required to complete the cruise phase within the 18 month period. A flight dynamics analysis was conducted to determine the ΔV required for each deterministic transfer maneuver during the cruise phase. A summary of the ΔV maneuvers is provided in Table 1.2-4.

Table 1.2-4: Propulsion ΔV Budget

LISA PM Δ v Budget	
Maneuver	**Δ v (m/s)**
Launch	0
Deterministic Transfer Maneuver 1	489
Deterministic Transfer Maneuver 2	50
Deterministic Transfer Maneuver 3	559
LV Contingency	32
Total =	1130

1.2.4 Propulsion System Design Alternatives

The baseline design is considered the best path forward because it is NASA Class B mission compliant (single fault tolerant) system. However, there are several Class B alternatives that would increase reliability, and there are Class C alternatives that would yield cost and mass reductions if the level of risk is considered acceptable or a system failure is deemed non-credible. The final design will have to weigh the cost and mass benefits against the failure probabilities of a Class C mission design. These alternatives were captured in the GSFC, LISA Mission Design Lab Studies conducted in Jan and Mar 08.

1.2.5 Propulsion System Hardware

Table 1.2-5 provides a Propulsion System hardware summary. The components and performance specs listed below represent candidate hardware that might be used in the final

LISA Propulsion System design. Hardware information accuracy will improve as the Propulsion System design matures.

Table 1.2-5: Propulsion System Hardware Summary

Component	Qty
Hz Tank	1
NTO Tank	2
He Tank	1
445N (100lb) Main Engine	1
Hz Valve (dual coil)	1
NTO Valve (dual coil)	1
Injector heater	1
22N (5lb) Hz Thruster	8
Hz valve (series redundant	1
Hz valve heaters (primary/ redundant)	1
Catbed heater (primary/ redundant)	1
Pressure Regulator	2
Ti, 3/8”, HP Latch Valve	2
Ti, ¼”, ACS Thruster Isolation Latch Valve	2
Ti, 3/8”, LAE Isolation Latch Valve	2
Ti, Parallel Redundant Check Valves	5
Ti, NC Pyrovalves HP/LP	10
Ti, HP, He Filters (10μ)	1
Ti, LP, He Filters (10μ)	2
Ti, 3/8”, Propellant Filters (15μ)	3
Ti, LP/HP/He/Propellant Fill/Drain Valves	7
Ti, HP/LP Pressure Transducer	9

Source: MDL Jan 08

1.3 Electrical Design

The electrical architecture for the bi-propellant system consists of thruster drive electronics and harness, the heaters and thermostats required for thermal control, and required sensors. The functions of these items will be controlled by the S/C C&DH integrated avionics. The power required for opening the thruster valves during operation and to provide thermal control to the propellant tank(s) and lines will be provided by the S/C Electrical Power System to eliminate duplication of functionality.

1.4 P/M Thermal Design

The primary function of the P/M thermal design is to maintain an operating temperature environment for the P/M propulsion and ACS systems during the cruise phase. The secondary function of the propulsion module thermal design is to assist Sciencecraft instrument survival heating during the cruise phase. To achieve both functions, the following passive and active thermal control components will be employed:

- Multi-Layer Insulation (MLI) on all fuel lines, fuel tanks and thrusters
- MLI and Ge coated Black Kapton on P/M shell exterior
- MLI and Single Sided Aluminum Kapton on P/M shell interior
- Tayco Kapton film heaters mounted on all fuel tanks, fuel lines and thrusters
- Thermostats and YSI 44910 thermistors used for temperature regulation
- Heater controller card integrated in S/C C&DH system with associated software

1.4.1 Propulsion Module Shell Insulation Design

If properly insulated, the propulsion module shell can provide an effective thermal barrier between the S/C and the cold depths of space. Carefully designed insulation blankets on the exterior and interior surfaces will ensure maximum absorption of heat from the sun and maximum retention of heat inside the S/C envelope respectively.

1.4.2 Fuel Line Thermal Regulation Design

Temperature regulation must be applied to all fuel lines to ensure proper fuel delivery to the thruster nozzles. To achieve this, heater circuits and MLI will be wrapped around each fuel line. The fuel line thermal design is illustrated in Figure 1.4-1.

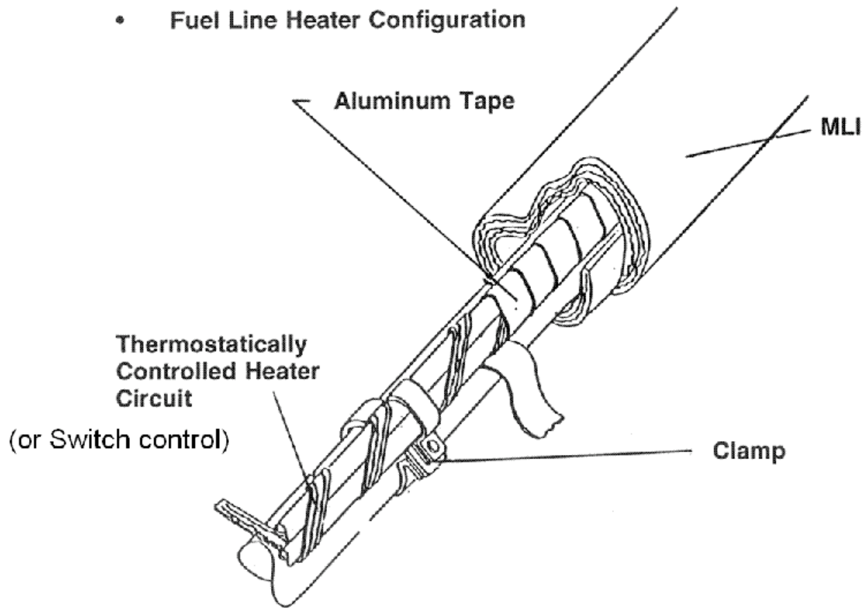


Figure 1.4-1: Fuel Line Thermal Design

1.4.3 THERMAL POWER REQUIREMENTS

The S/C thermal design will impose a significant demand on the EPS during the cruise phase, during which time survival heater power draw will be at a maximum. The total power required for thermal regulation during the cruise phase is estimated to be 168.6 W. Refer to Table 1.4-1 for a breakdown of estimated survival heater power requirements for the payload, Sciencecraft and propulsion module.

Table 1.4-1: Survival Heater Power Requirement Estimates

Payload Survival Heater Power Requirements	
Component	Power (W)
LOCS Instrument	35
LIMAS Instrument	15
Total	50
Sciencecraft Survival Heater Power Requirements	
Component	Power (W)
Laser Amp Electronics (x2)	10

Phase Meter Electronics (x2)	2	
Laser Unit (x2)	20	
Charge Mgmt. System (x2)	4	
GRS Front End Elec. Box (x2)	14	
Total	50	

Propulsion Module Heater Power Requirements

Component	Power (W)	
Exterior Fuel Lines	6	
Interior Fuel Lines	3.2	
Fuel Tanks (2x NTO, 2x Hz)	28	7 Watts per tank
Pressure Transducers	3.4	
F&D	1.2	
Thruster Valves	16.8	2.1 Watts per 22N(5lb) Thruste
Star Trackers (x2)	10	
Total	68.6	
Total S/C Heater Power Req'd	168.6	

Source: MDL Jan 08

1.5 P/M Attitude Control System (ACS)

Mission baseline parameters driving the LISA P/M Attitude Control System (ACS) Design are referenced in Table 1.5-1.

Item/Function	Requirement	Comments
Orbit Transfer control	Provide attitude control for 15 months during the cruise phase	Requirement for sufficient ACS fuel budget and suitable thruster size/number/orientation
Contamination	The payload must be protected from contamination at all times	The thruster plumes from all elements of the ACS system must not impinge on or contribute to contamination of the payload

Table 1.5-1: P/M ACS Driving Requirements

1.5.1 P/M ACS Overview

Attitude control of the S/C throughout all mission phases leading up to Sciencecraft deployment will be handled by the P/M ACS. The P/M ACS will use eight 22N (5lb_f) axial monoprop Hz thrusters tied into the P/M dual mode propulsion system to provide pitch, yaw and roll control during all orbital transfer maneuvers. P/M ACS sensing will come from Coarse Sun Sensors (CSS) and Star Trackers Camera Head Units (ST CHU) installed on the P/M. The Sciencecraft C&DH system will provide power and data handling for the P/M ACS system. Section 1.1.2.3 shows ACS component mounting accommodations. The P/M ACS components are the same as those used on the Sciencecraft. Refer to the Sciencecraft Description Document ACS section for performance information.

1.5.2 ACS Sensing

The P/M attitude control system will use sun sensors to acquire the sun as required during orbit transfer maneuvers during the cruise phase. The sun sensors will also function as a backup system to restore the S/C to a safe-hold position in response to an anomalous event should the star trackers fail to do so. Star trackers will function as the primary sensors for attitude determination to guide the S/C through the cruise phase.

1.5.2.1 Coarse Sun Sensors

Preferred over digital sun sensors for their lower mass and cost, the Coarse Sun Sensors (CSSs) will be more than adequate for safe-holding the S/C while the STs provide the first line of defense for anomaly detection. The P/M CSS system will share an analog card interface in the C&DH unit with the Sciencecraft CSS system. A total of six CSSs will be installed on the P/M. Four of the six CSSs will be installed on the top side of the ACS thruster mounting bracket. The remaining two CSSs will be installed on the bottom side of the ACS thruster mounting bracket. The P/M CSSs will be the same model as those used on the Sciencecraft.

1.5.2.2 Star Trackers

Two Star Tracker (ST) Camera Head Units (CHUs) will be mounted on the P/M shell. A 60 degree spacing of the P/M ST CHUs results in overlapping fields of view (FOVs) to provide hot redundant attitude sensing data. The P/M ST head units will be the same model as those used on the Sciencecraft. The Sciencecraft ST processing units will handle data from the P/M ST CHUs in a cross-strapped configuration.

An alternative design would eliminate the P/M mounted ST head units by providing a viewing port through the P/M shell to allow Sciencecraft ST functionality during all mission phases.

Refer to the Sciencecraft Description Document, ACS section, for more details regarding this trade study.

1.5.3 ACS Thrusters

The P/M ACS will use eight Aerojet MR-106L monopropellant 22N (5lb$_f$) thrusters configured into two strings of four thrusters canted at 15 degrees to provide a specific impulse of 275 sec. The P/M ACS thrusters will be mounted on brackets installed on the P/M shell exterior as shown in Figure 1.2-4. The P/M shell will function as a barrier to ensure P/M ACS thruster plume does not impinge upon the payload or contribute to payload contamination. Details about the P/M ACS thrusters are provided in Section 1.2.

1.6 P/M Communication System

Mission baseline parameters driving the LISA P/M Communication System Design are referenced in Table 1.6-1.

Item/Function	Requirement	Comments
Command & Telemetry during LEOP	X-Band Omnis, 90 kbps downlink, 2 kbps	

Table 1.6-1: P/M Communication System Driving Requirements

1.6.1 P/M Communication System Overview

The P/M Communication System consists of two omni-directional antennas mounted on brackets on the P/M shell exterior. The omni antennas are the primary communication channel during the LEOP and cruise phases of the mission until the distance from the Earth is too great for nominal communications – at this point the HGA antennas on the Sciencecraft take over. The omni-directional antennas on the P/M are still available for low rate communications should problems occur during transfer. Power supply and C&DH functions for the P/M omni antennas are provided by the Sciencecraft EPS and C&DH systems.

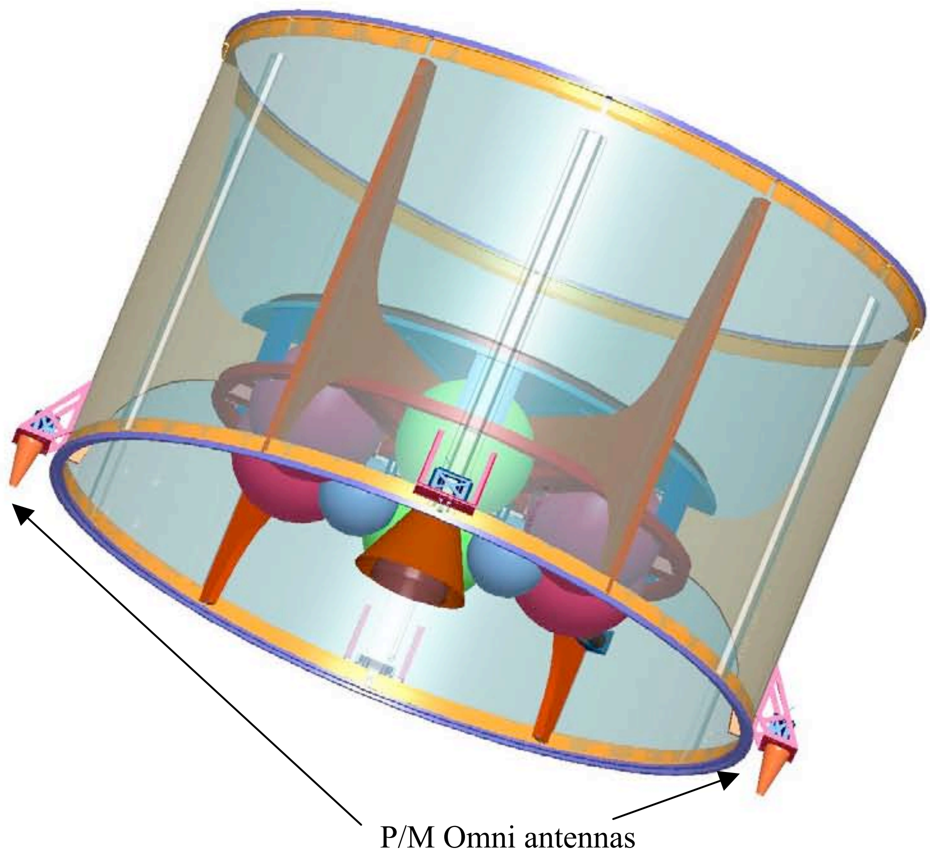


Figure 1.6-1: P/M Omni Antenna Installation

LISA ACRONYMS

ACS	Attitude Control System
ADC	Analog to Digital Converter
AIT	Assembly, Integration, and Test
AIVT	Assembly, Integration, Verification and Test
AL	Aluminum
AST	Analog Star Trackers
AU	Astronomical Unit
CCD	Charge-Coupled Device
C&DH	Command & Data Handling
cFE	Core Flight Executive
CFLR	Centaur Forward Load Reactor
CFRP	Carbon Fiber Reinforced Plastic
CFS	Core Flight System
CHU	Camera Head Unit
CMS	Charge Management System
CSS	Coarse Sun Sensor
CST	Composite Support Tube
CTE	Coefficient of Thermal Expansion
CMNT	Colloidal Micro-Newton Thrusters
CPB	CPU Power Block
DAC	Digital to Analog Converter
DFACS	Drag Free Attitude Control System
DFC	Drag Free Control
DoD	Depth of Discharge
DPLL	Digital Phase Locked Loop
DRS	Disturbance Reduction System
DSN	Deep Space Network
DTM	Deterministic Transfer Maneuver
DSS	Digital Sun Sensors
EADS	European Aeronautic Defense and Space Company
EM	Engineering Model
EOL	End of Life
ESA	European Space Agency

FDIR	Failure Detection Isolation and Recovery
FM	Flight Model
FoV	Field-of-View
FTR	Final Technical Report
FPA	Fiber Power Amplifier
GsAs	Gallium Arsenide
GRS	Gravitational Reference Sensor
GSFC	Goddard Space Fight Center
HGA	High Gain Antenna
KSC	Kennedy Space Center
FEEP	Field Emission Electric Propulsion
FPGA	Field Programmable Gate Array
FWHM	Full Width Half Maximum
FSW	Flight Software
H/W	Hardware
Hz	Hydrazine
ICD	Interface Control Document
IMS	Interferometry Measurement System
Isp	Specific Impulse
IWS	Inertial Wavefront
JPL	Jet Propulsion Laboratory
LAE	Liquid Apogee Engine
lb_f	Pounds-Force
LEOP	Launch and Early Operations Phase
LGA	Low Gain Antenna
LIMAS	LISA Instrument Metrology and Avionics System
LiIon	Lithium Ion
LISA	Laser Interferometer Space Antenna
LNP	Low Noise Amplifier
LO	Local Oscillator
LOC	Lines of Code
LOCS	LISA Optomechanical Core Systems
LOS	Line of Sight
LPF	LISA Pathfinder
LTP	LISA Technology Package
MDL	Mission Design Lab (GSFC)
MEOP	Maximum Expected Operating Pressure
MLB	Motorized Lightband
MLI	Multi-Layer Insulation
MOC	Mission Operations Center
MOFA	Master Oscillator Fiber Amplifier
MOPA	Master Oscillator Power Amplifier
MOU	Memorandum of Understanding
MRD	Mission Requirements Document
N	Newtons

NASA	National Aeronautics & Space Administration
Nd:YAG	Neodymium doped Yttrium Aluminum Garnet
NEA	Noise Equivalent Angle
nm	Nano-metre (10^{-9}m)
NPRO	Non-Planar Ring Oscillator
NTO	Nitrogen Tetroxide
OA	Optical Assembly
OB	Optical Bench
OATM	Optical Assembly Tracking Mechanism
OSR	Optical Surface Reflectors
PAA	Point Ahead Actuator
PAF	Payload Adapter Fitting
PL	Payload
PLF	Payload Fairing
pm	pico-metre (10^{-12}m)
PM	Proof Mass
P/M	Propulsion Module
PV	Photo Voltaic
QPD	Quad Photo Diode
SA	Solar Array
S/C	Spacecraft
ScRD	LISA Science Requirement Document
SDPS	Science Data Processing Segment
SIB	Spacecraft Interface Block
SNR	Signal to Noise Ratio
SRS	Shock Response Spectrum
SSPA	Solid State Power Amplifier
ST	Star Tracker
TBD	To be Determined
TBR	To be Resolved
TBS	To be Supplied
TCM	Trajectory Correction Maneuver
TDI	Time Delayed Interferometry
TM/TC	Telemetry/Telecommand
TWTA	Traveling Wave Tube Amplifier
RMS	Root Mean Square
UPB	Unswitched Power Block
USO	Ultra Stable Oscillator
UV	Ultra Violet
W	Watts
wrt	…with respect to
Yb:YAG	Ytterbium doped Yttrium Aluminium Garnet

End of Document